Distributed Beamforming for PHY Layer Secret Communication

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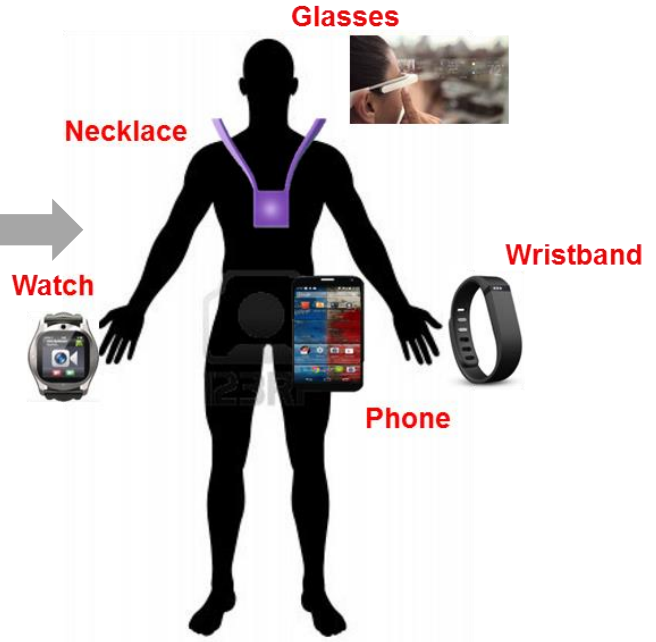
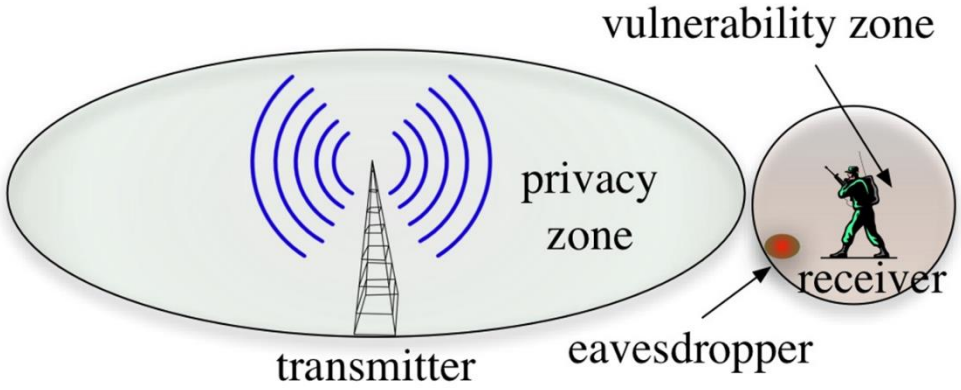
Secret Communication is Important

Eavesdropping

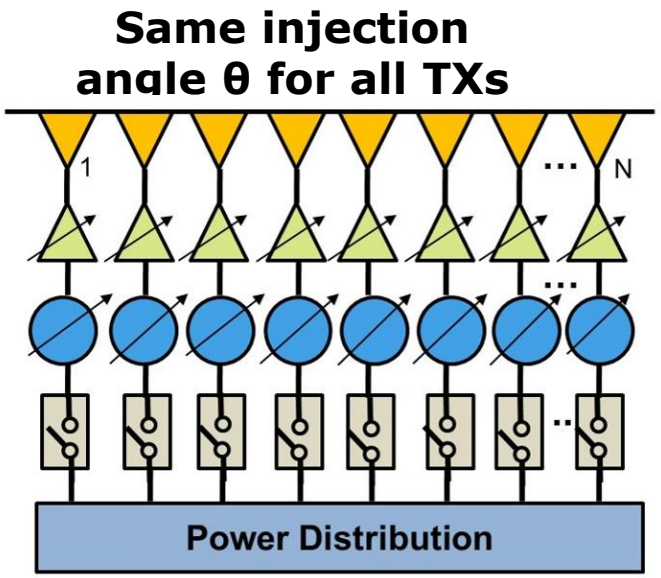


Cryptography and PHY Layer Security

- **Cryptography**
  - **- At the cost of lowering data rate**
  - **- Computationally expensive**
- **PHY layer security methods**
  - **+ Simple**
  - **+ Low overhead**
  - **+ Could Increase data rate**
  - **+ Could complement cryptography-based methods**

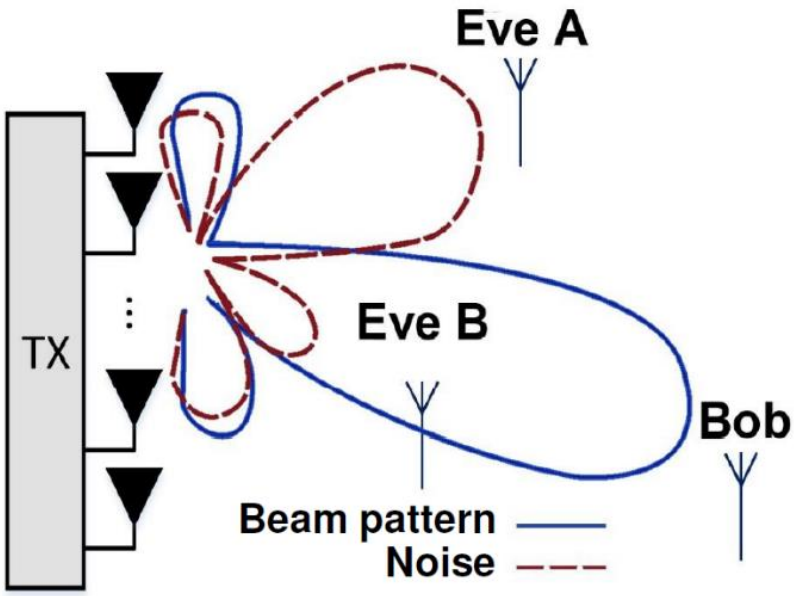


Traditional Beamforming



- A popular solution for PHY secret comm
- Clustered transmitters, faraway receiver
- Plane wave for transmitters
- Optimization based beamformer: MRC, ZF

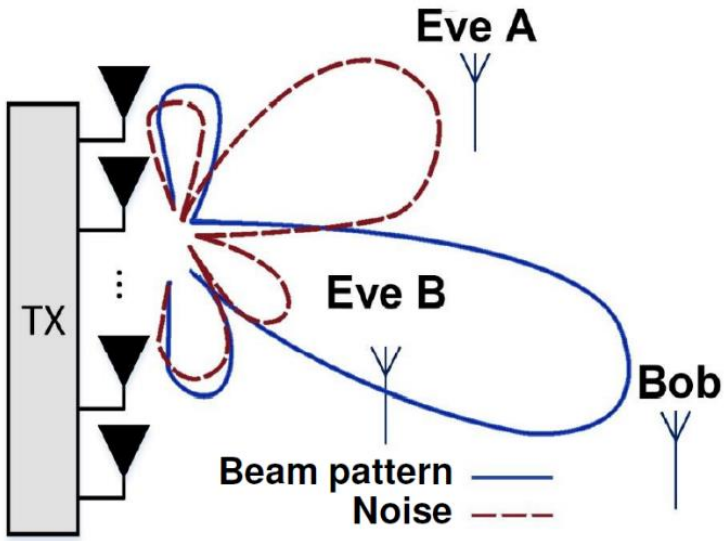
Beamforming for Secret Communication



- Generating a high energy beam towards Bob
  - Directionality
- Minimizing energy towards Eve
- Jamming Eve

Concerns in BF Secret Communication

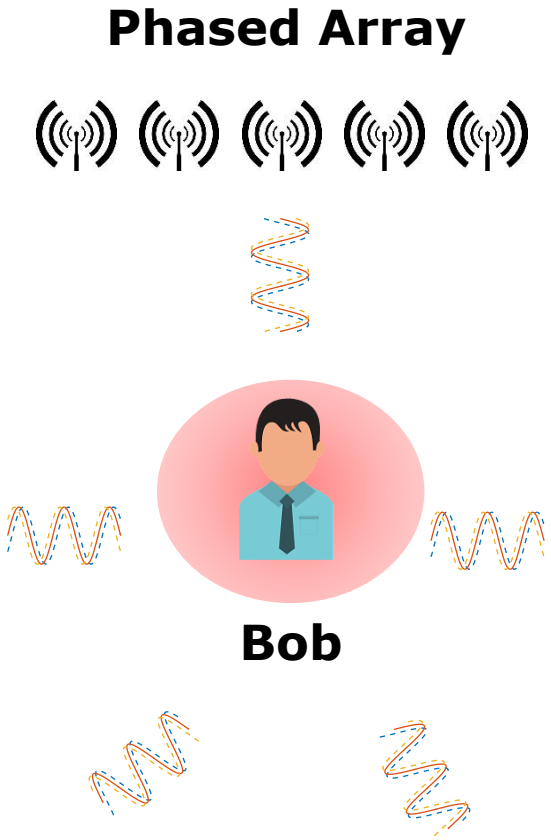
- Often assuming Eves' locations are known
  - Not practical
- High energy along the beam path
  - Eve B can overhear everything
- Introducing noise to jam Eves



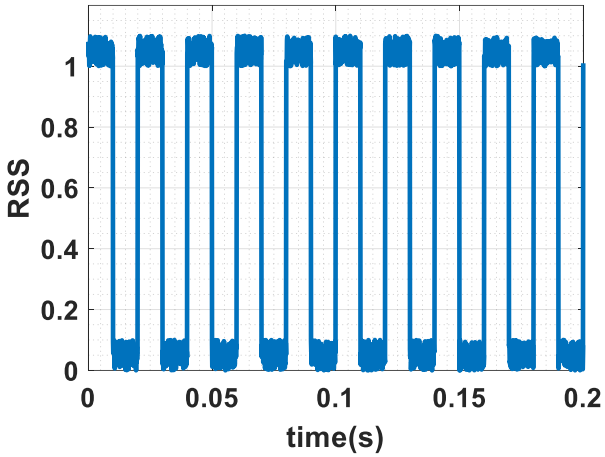
Overview of Secret-Focus

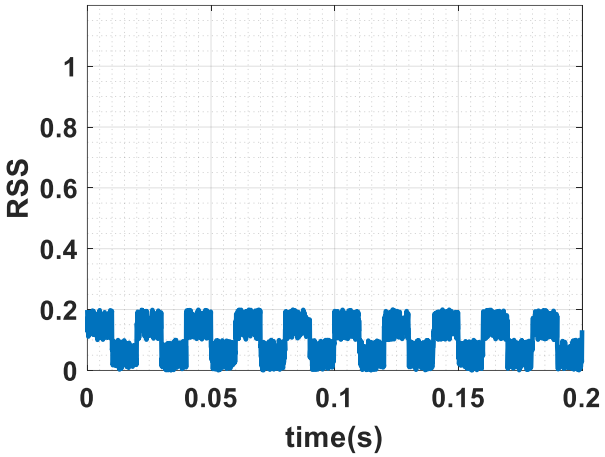
- **Distributed Transmitters**
  - No communication among transmitters
  - Distributed synchronization
  - Transmitters are not clustered, but distributed around the receiver

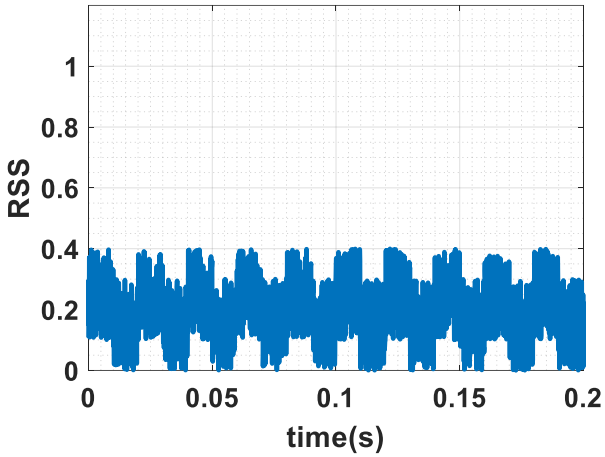
- **Distributed Phase Alignment (DPA) at the receiver**
  - Distributed Beamforming
  - Received signals are constructively added up at Bob

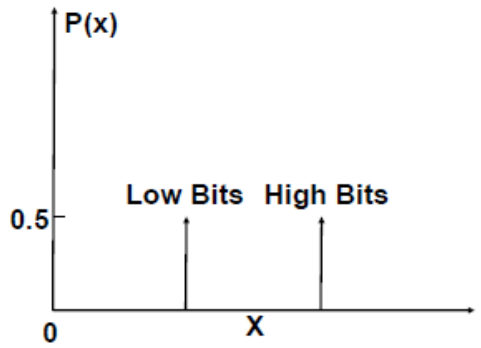


A Closer Look at Communication Bits

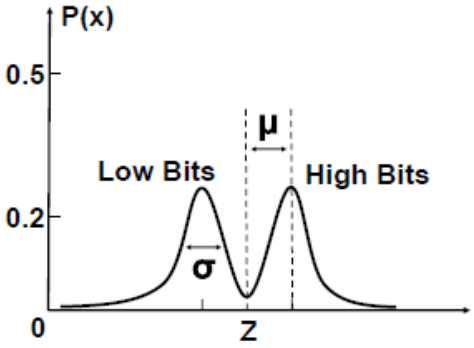








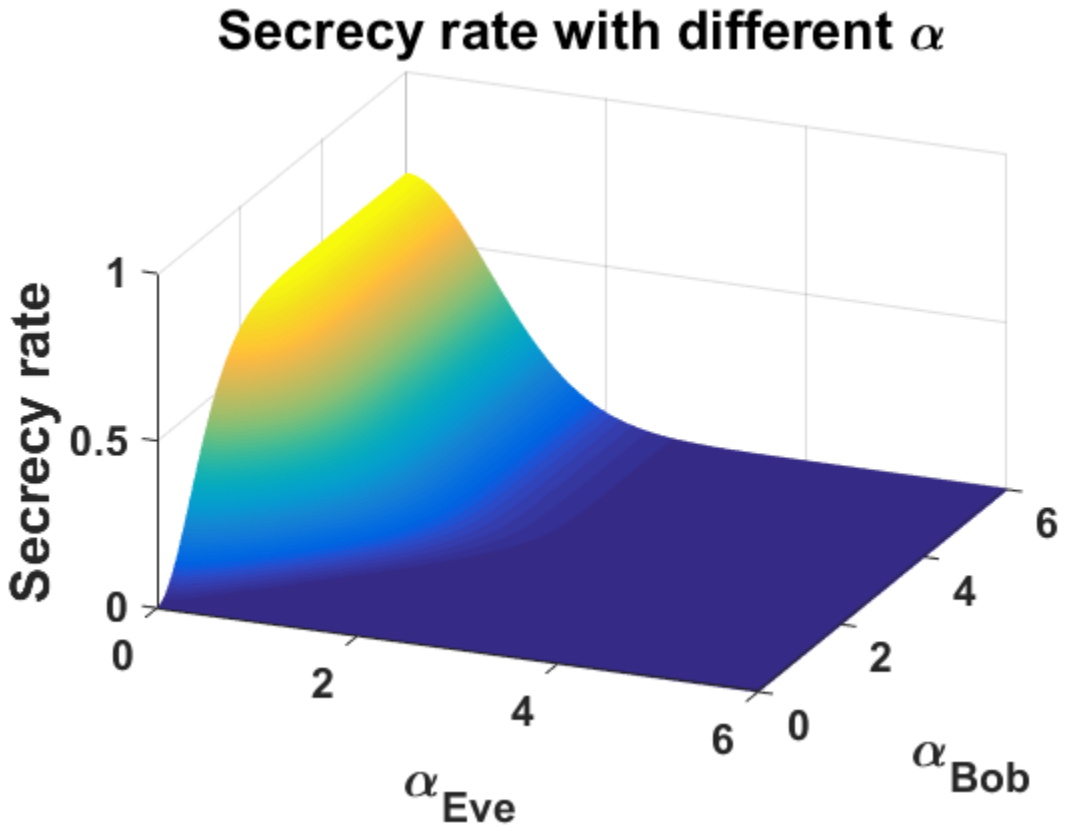
(a)



(b)

Def: Secret Communication Ratio(SCR): $\alpha=\mu/\sigma$

Secret Communication in Information Theory

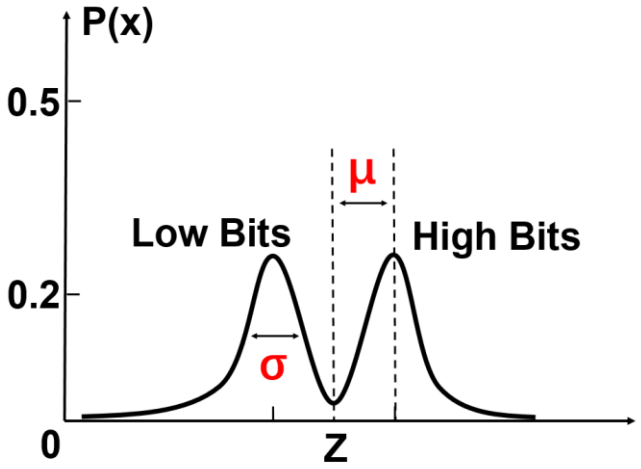


The lower α_{eve} and higher α_{bob} the better system secrecy rate

Secret Focus Design Goals

- The target location has the highest RSS, μ
- The target location has the lowest RSS variation, σ

Secret Communication Ratio(SCR): $\alpha=\mu/\sigma$

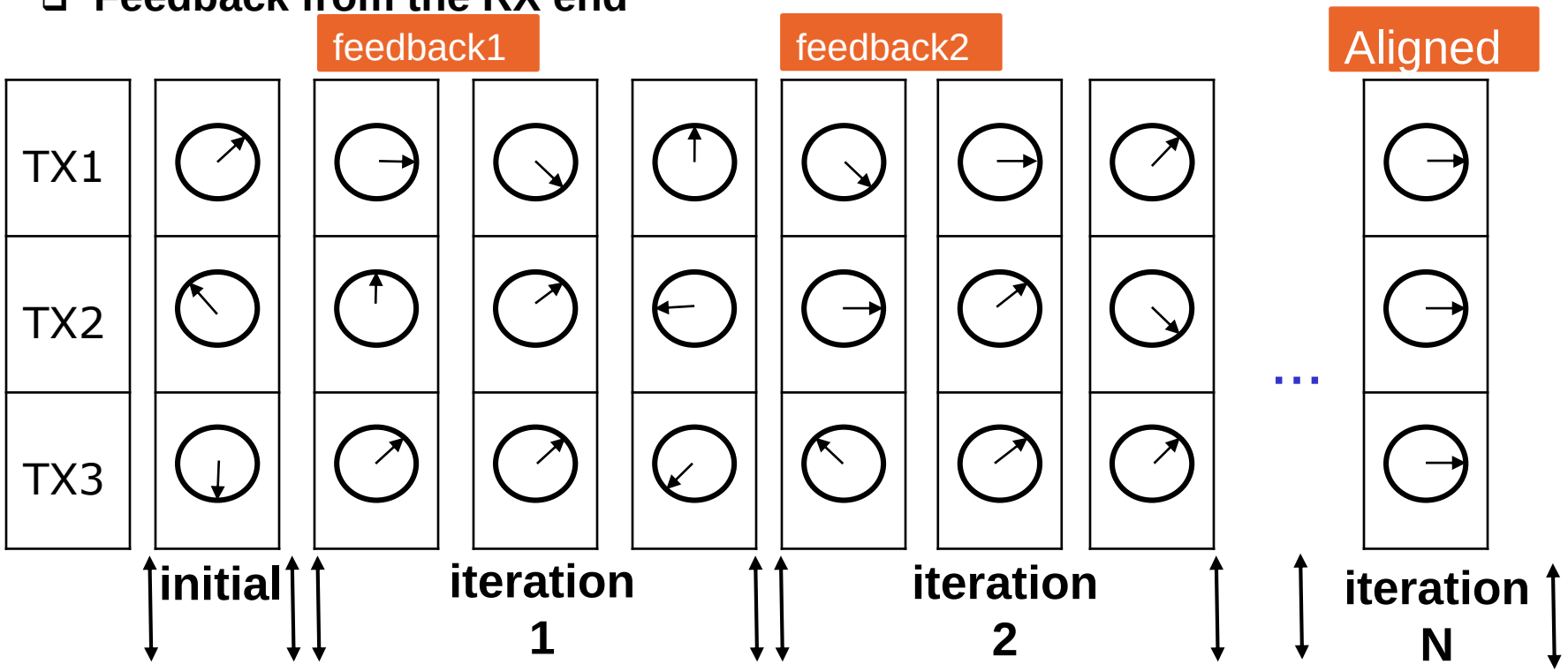


Secret-Focus Mechanism I

Combing phases of distributed transmitters at Bob

DPA through Feedback Control Loop

- **We choose a closed-loop feedback controlled phase alignment method**
  - **Random phase searching at the TX end**
  - **Feedback from the RX end**



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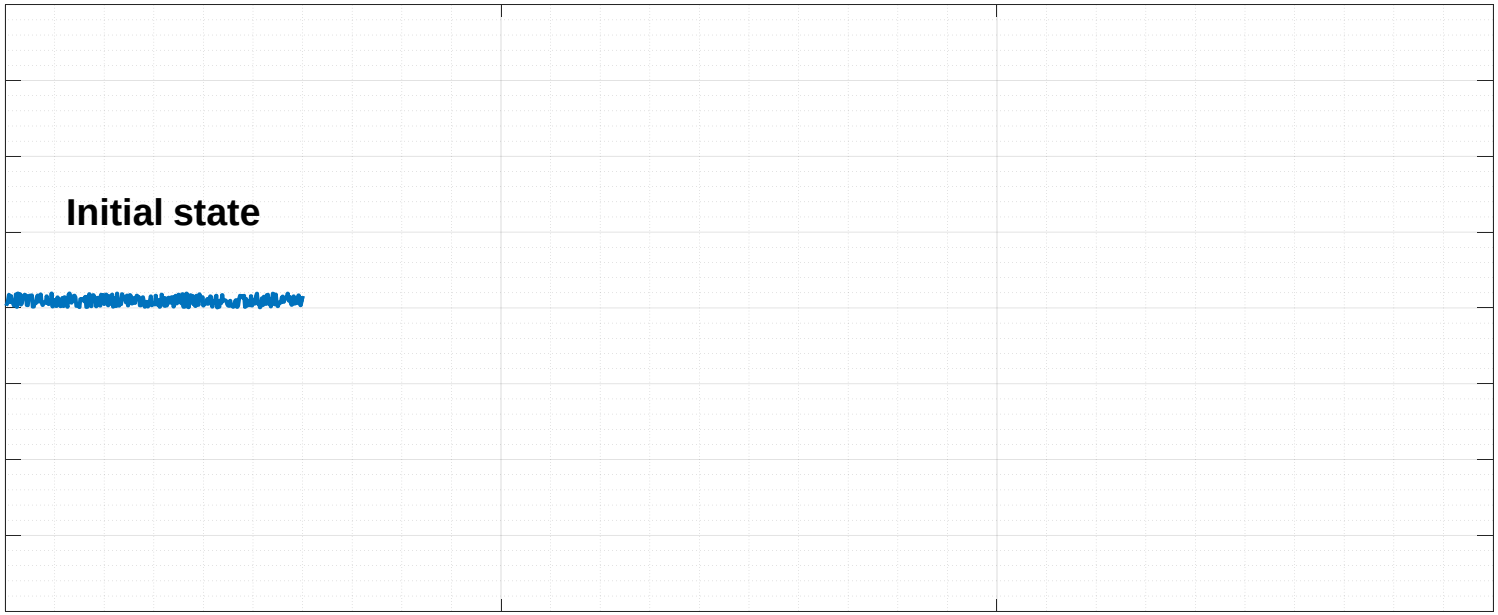

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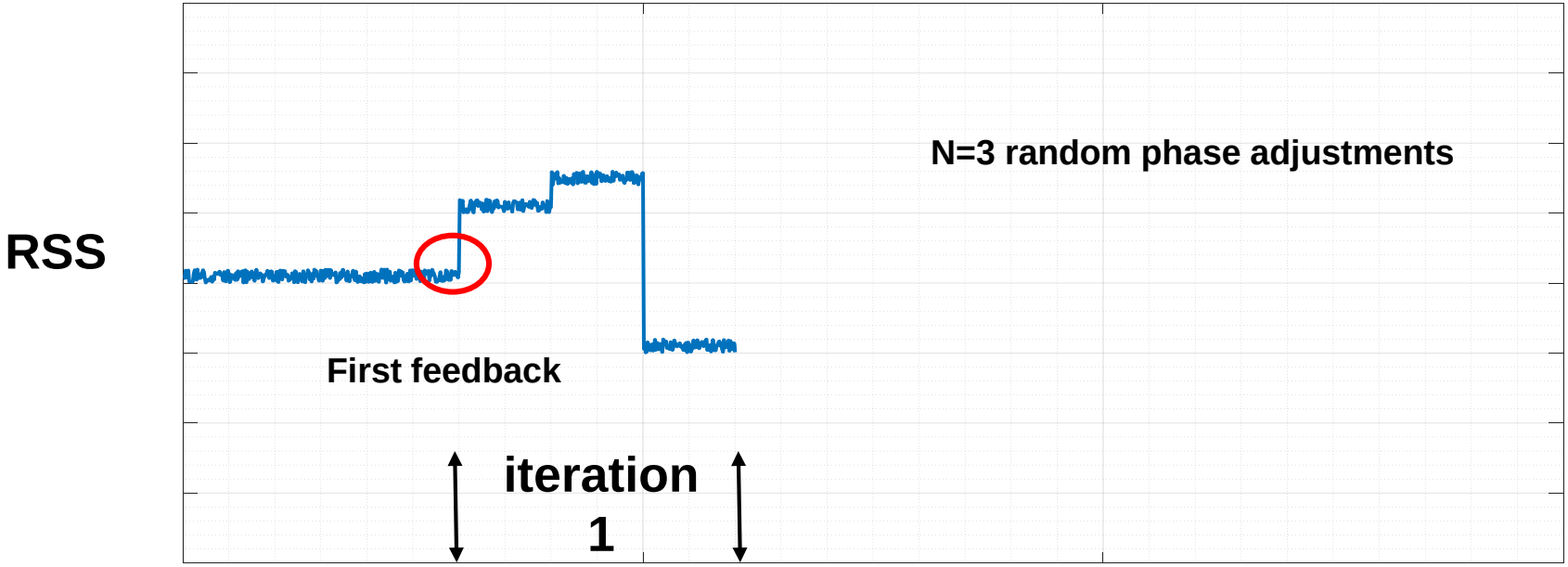

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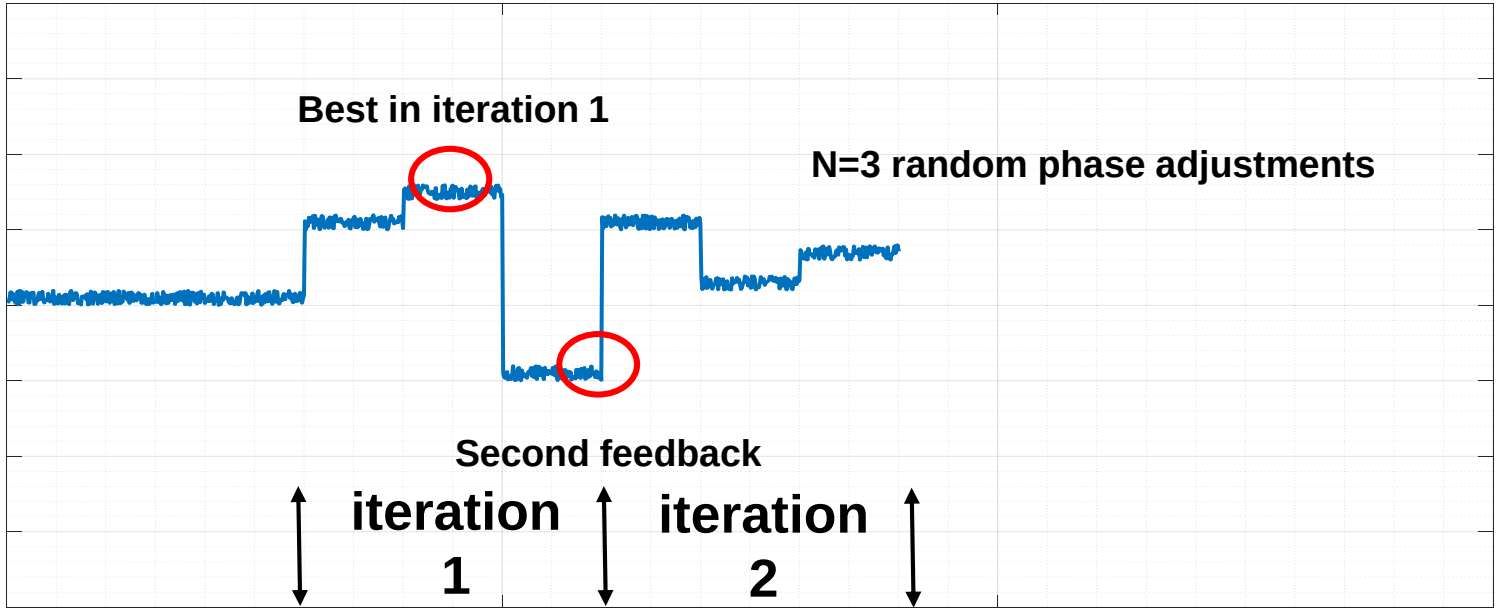

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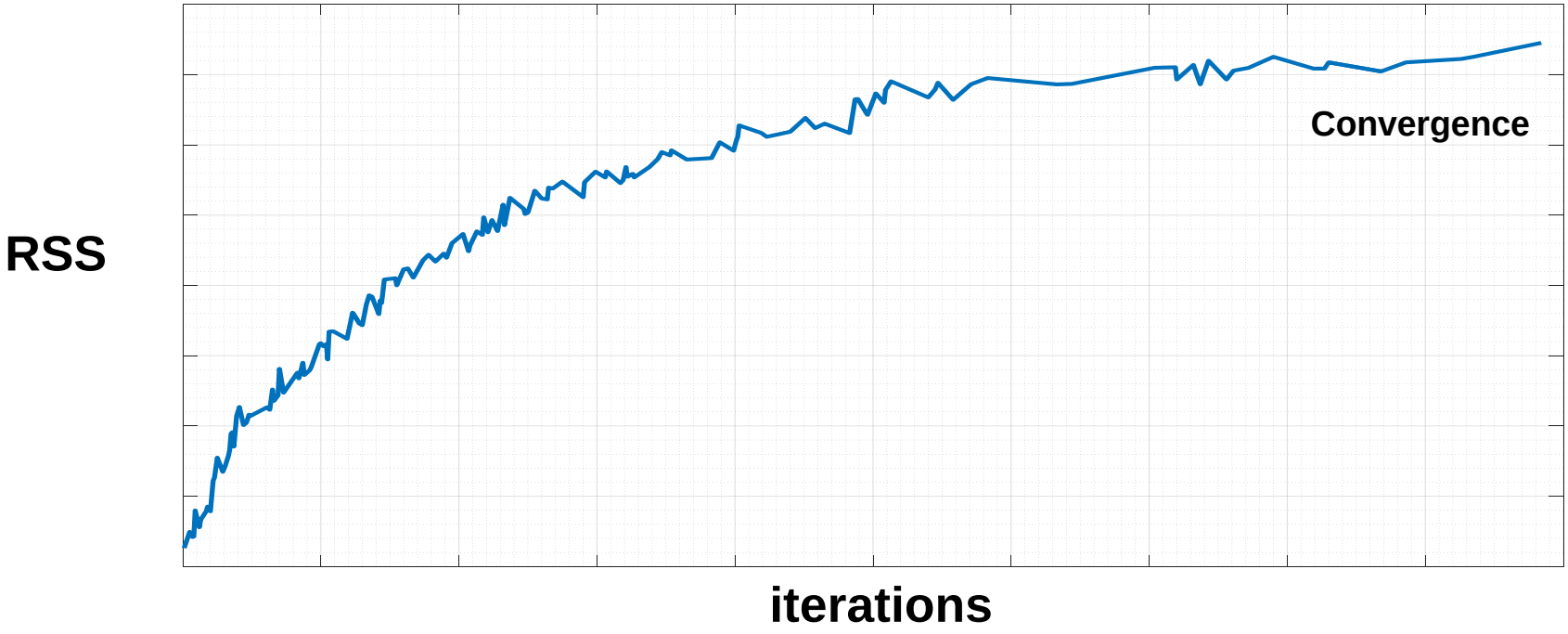
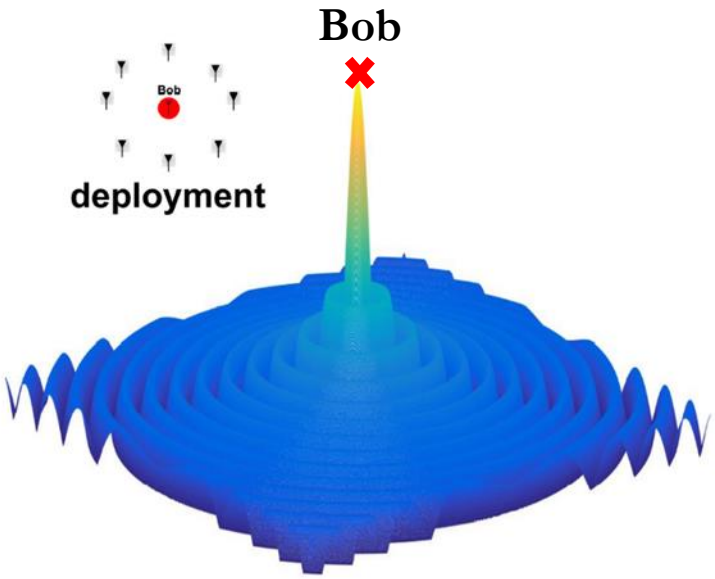


Energy Density Distribution

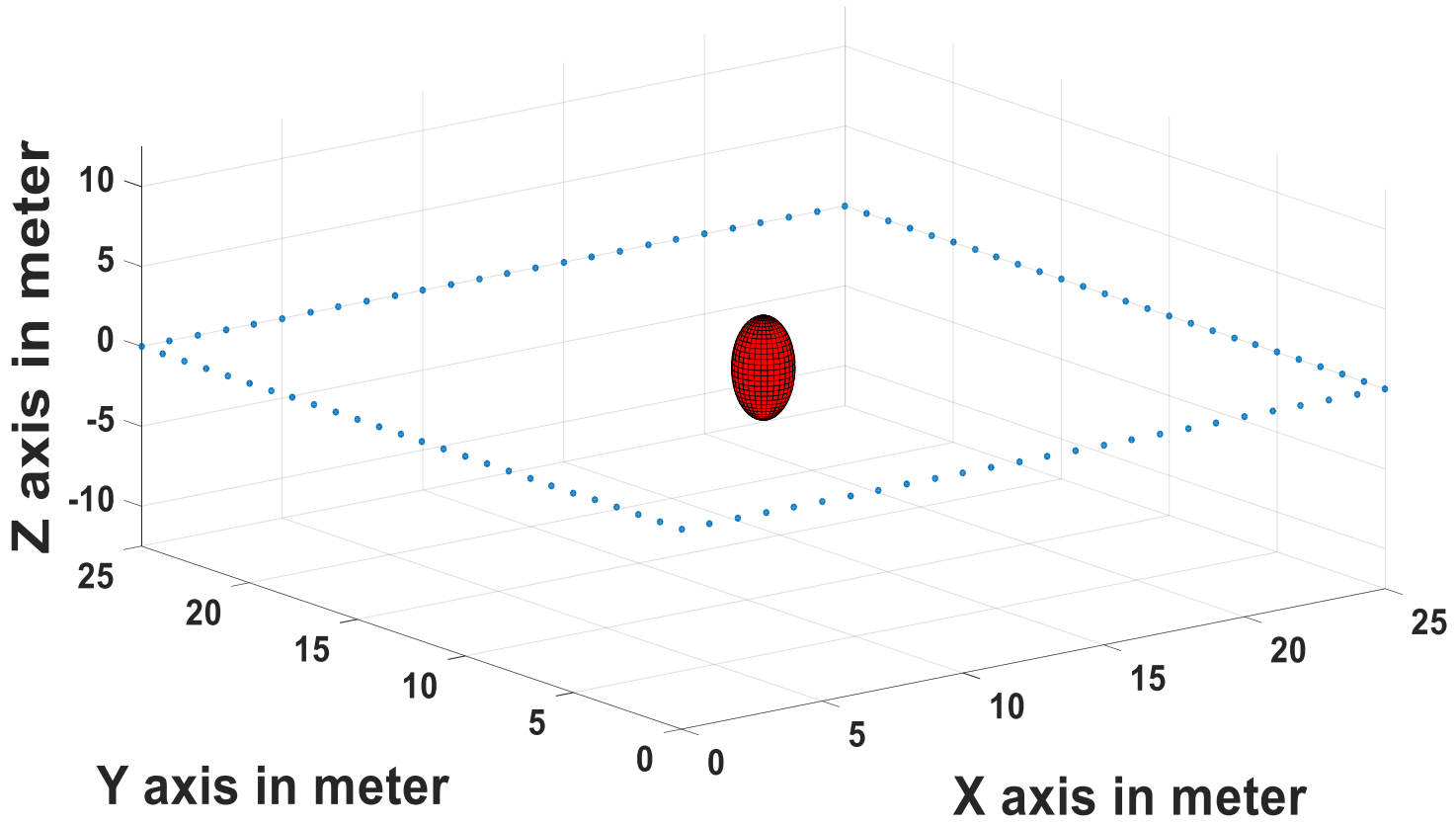
$$Y(d) = |\lim_{N\to\infty} \frac{R}{N} \sum_{i=1}^{N} \frac{1}{d} e^{j2\pi \frac{\sqrt{R^2+d^2-2Rd\cos\varphi_i}-R}{\lambda}}|, \varphi_i \in [0, 2\pi]$$

$$= \frac{R}{2\pi} \left| \int_0^{2\pi} \frac{e^{j2\pi \frac{\sqrt{R^2+d^2-2Rd\cos\varphi}-R}{\lambda}}}{\sqrt{R^2+d^2-2Rd\cos\varphi}} d\varphi \right|.$$



Bob has the highest μ!

A Spatial View of the 'Focused Energy'



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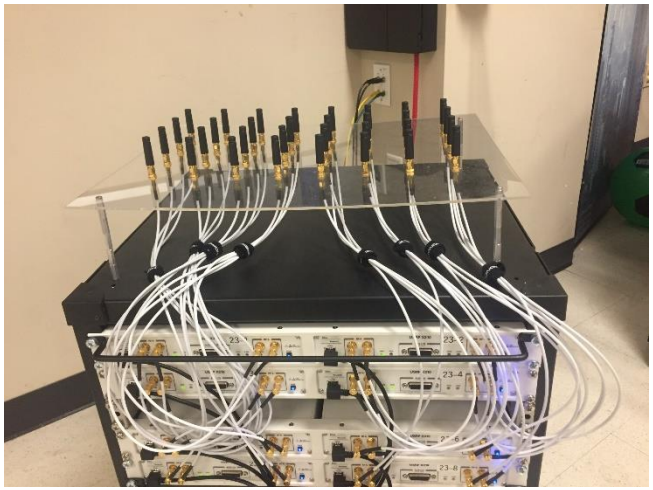
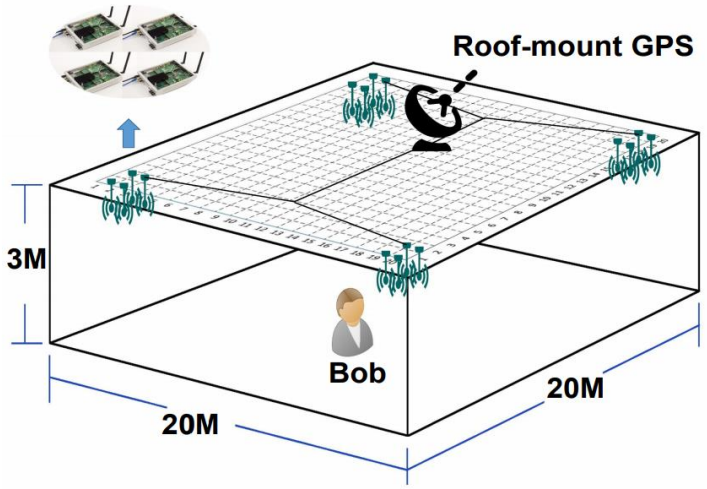
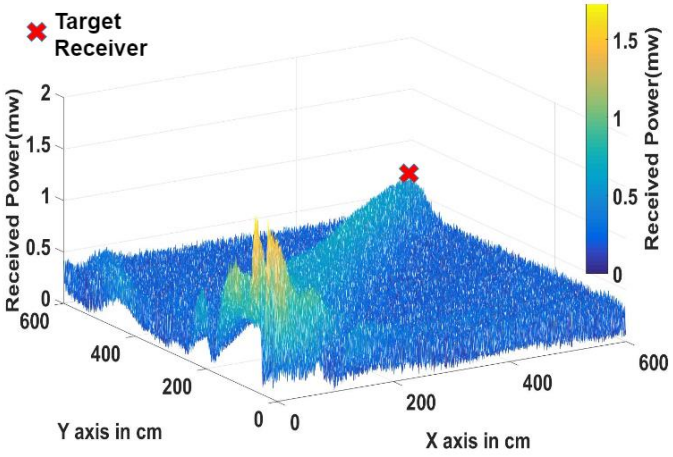
Orbit Testbed

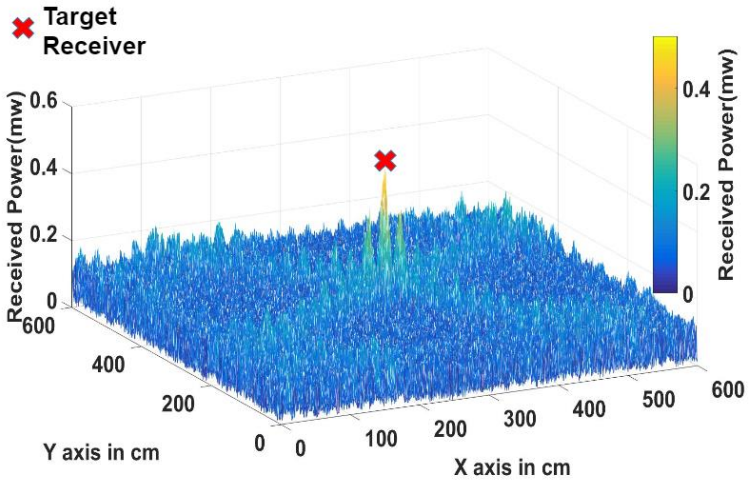
Experimental Measurements







Received power distribution in BF



Received power distribution in DPA

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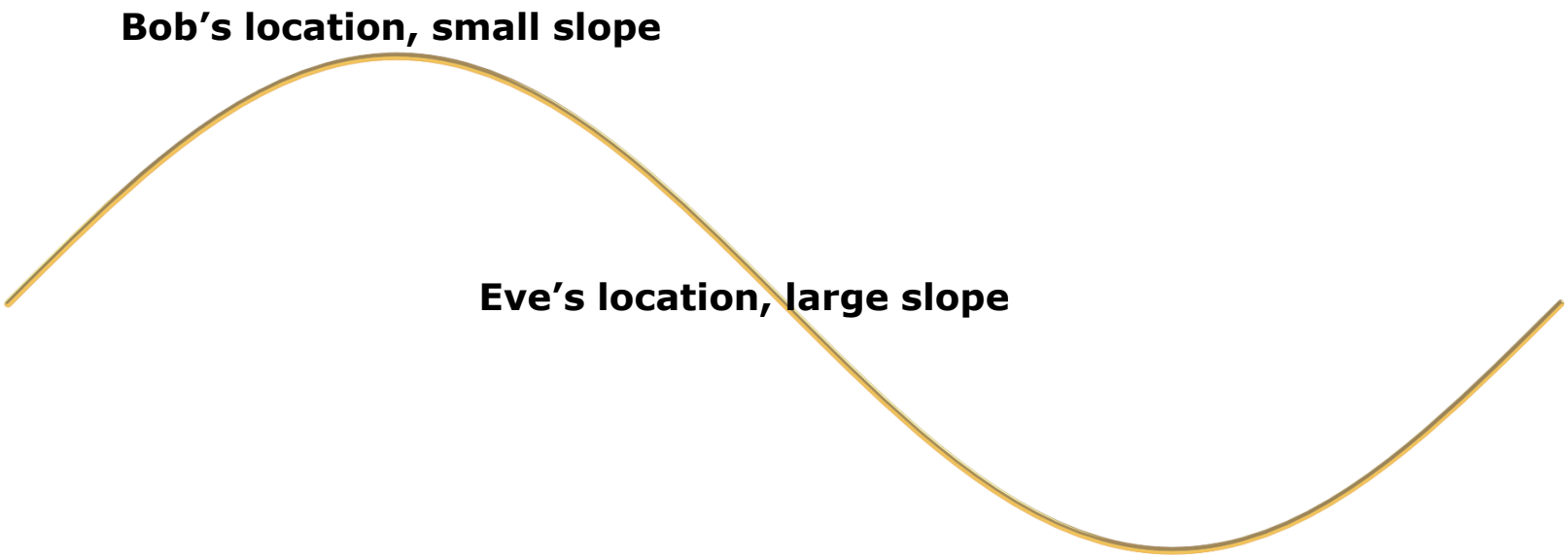
Secret-Focus Mechanism II

Dithering transmitters' phases around the alignment phases

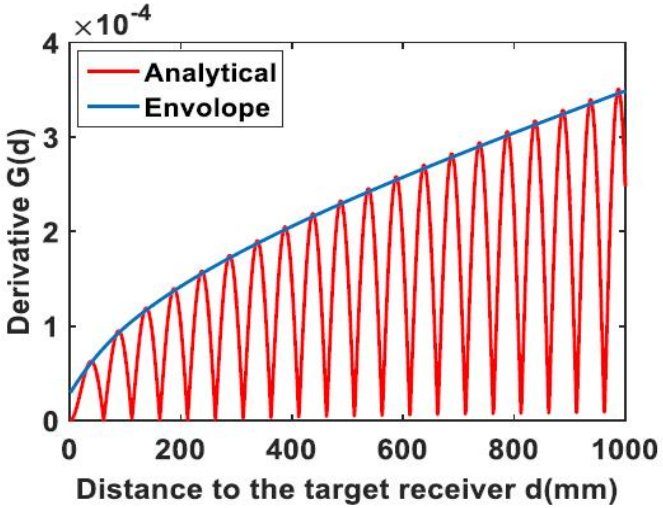


Intuition: relative 'flat' at sinusoid signal's peak.

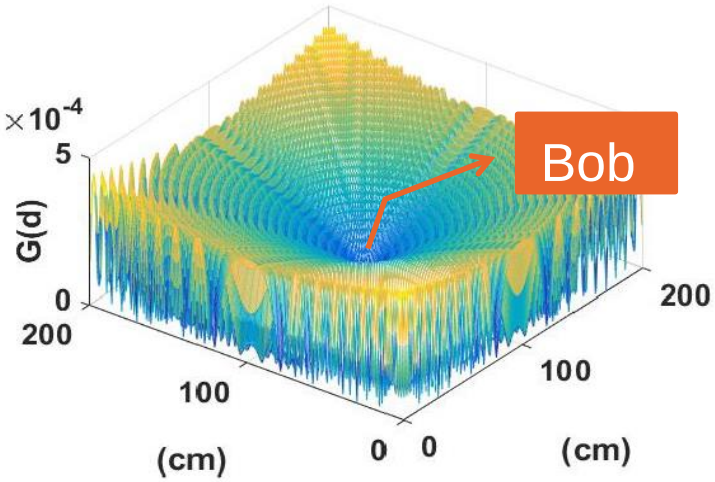
Phase Dithering

RSS derivative as a function of distance to Bob

$$G(d) = -2\int_0^{2\pi} \frac{\sin\left(2\pi\frac{\sqrt{R^2+d^2-2Rd\cos\varphi}-R}{\lambda}\right)}{(R-d)\sqrt{R^2+d^2-2Rd\cos\varphi}}d\varphi.$$



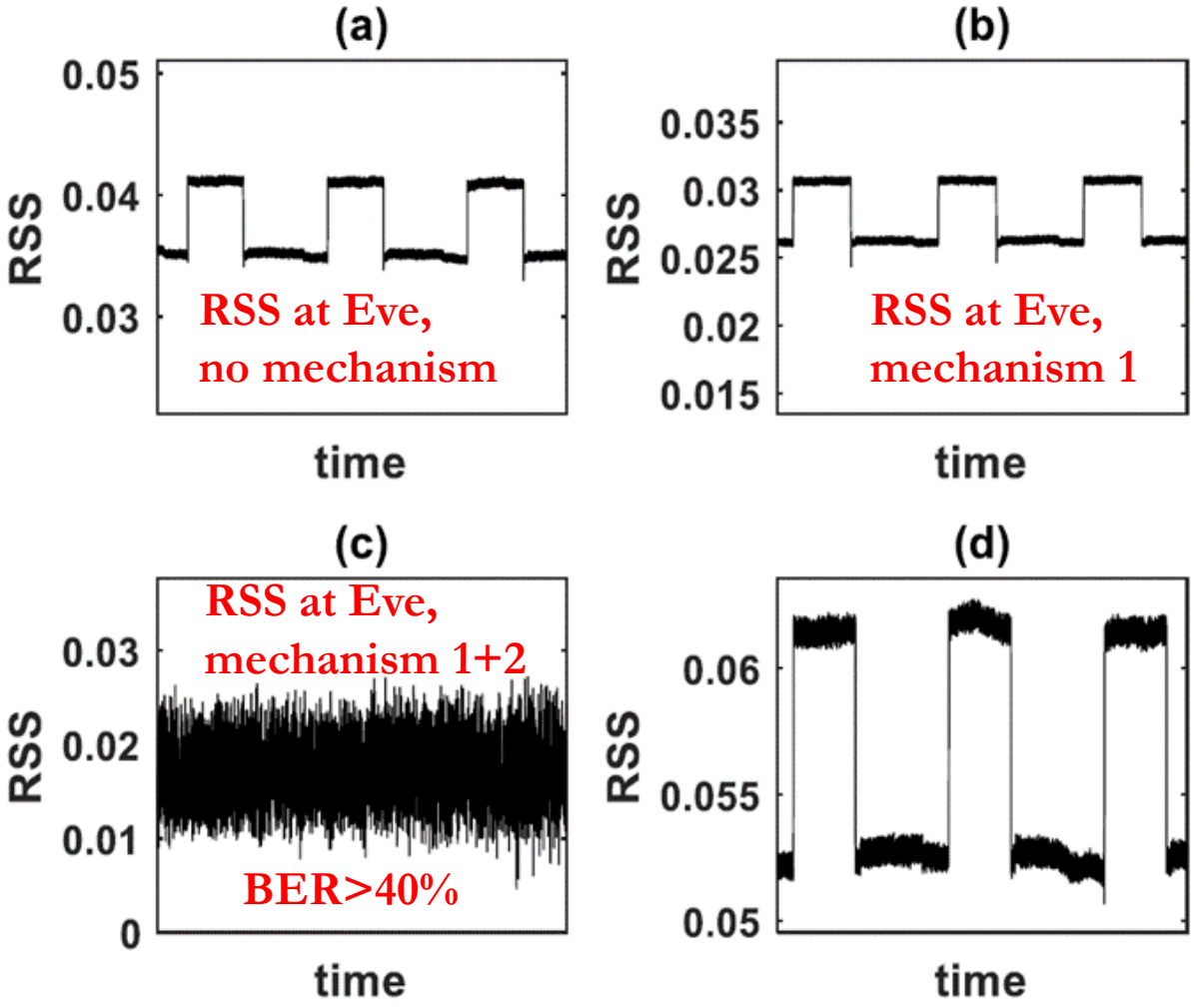
(a)



(b)

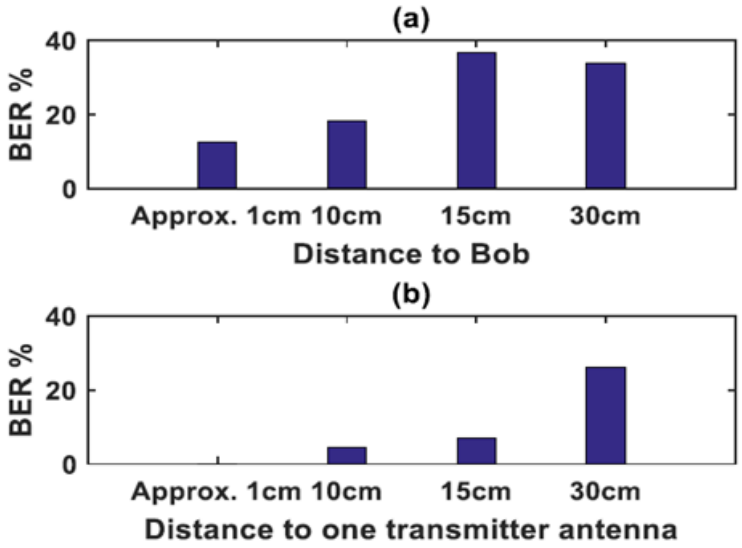
Bob has the lowest σ!

An Example Experiment

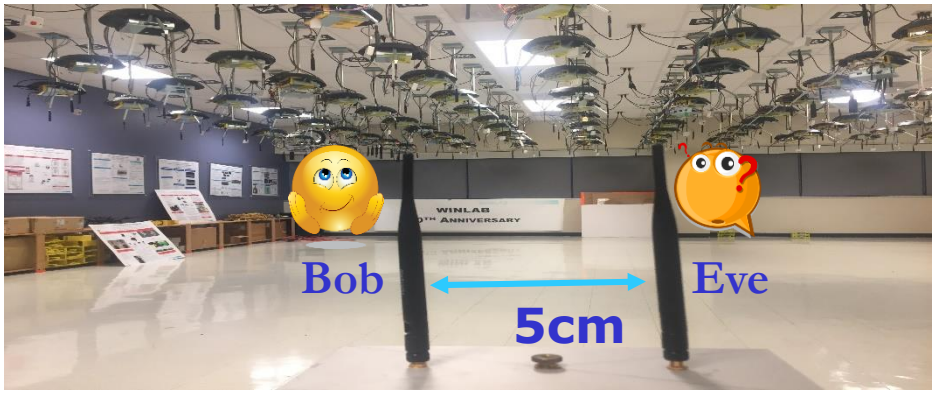


RSS at Bob, mechanism 1+2, BER=0

BER with Eve at Extreme Locations

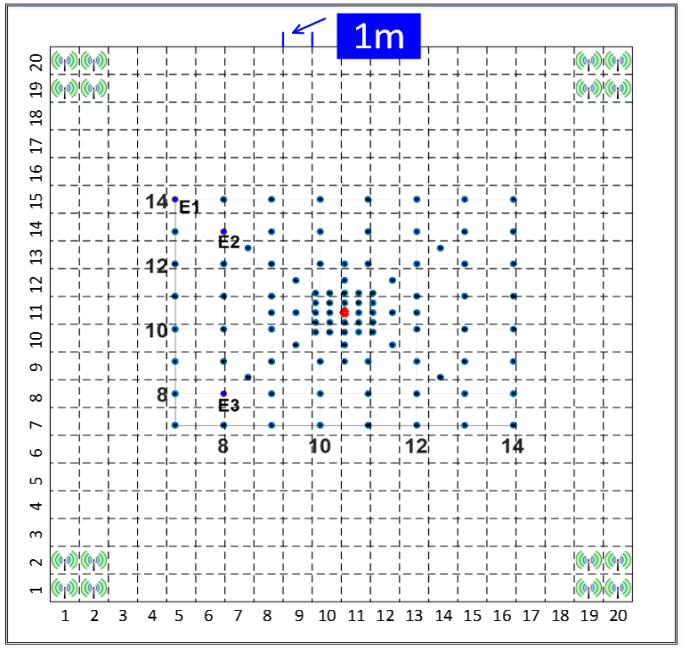


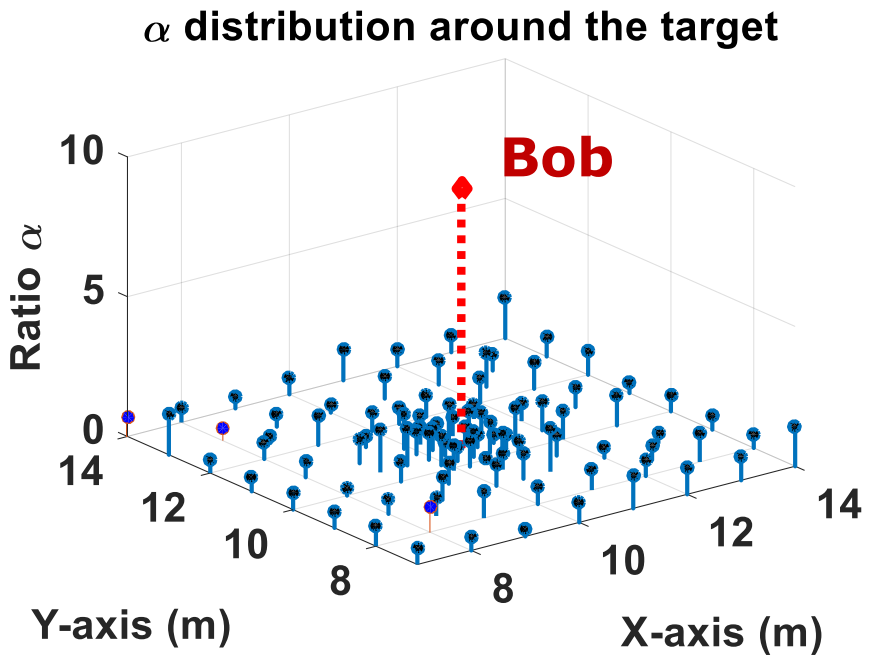
Extreme location test is the Achilles' heel of current PHY layer security approaches



Secret Communication Ratio Measurement

Measurement locations illustration





Bob has the highest α, Eves at other locations have very low α

Secret-Focus Summary

- A PHY layer secret communication approach
- No noise introduced
- Eves' locations are not necessary to be known
- Strong performance when Eve is placed at extreme locations

Thank you!

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typed to all terminals (use Ctrl+Shift+Insert to paste)

Multi-paste | Exit multi-execution mode

Sessions | Tools | Macros

phase_dith 0 1
ouput_on_off 0 1
beamf_on_off 0 1

phase_dith 0 1
ouput_on_off 0 1
dpa_on_off 0 1

phase_dith 0 1
ouput_on_off 0 1
dpa_on_off 0 1

phase_dith 0 1
ouput_on_off 0 1
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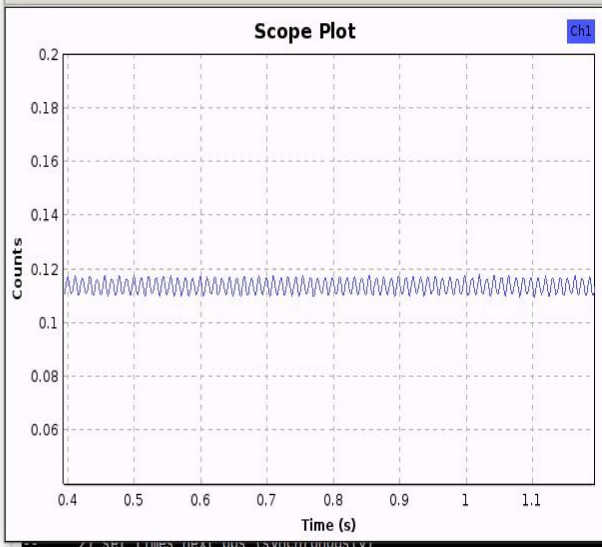
phase_dith 0 1
ouput_on_off 0 1
dpa_on_off 0 1

phase_dith 0 1
ouput_on_off 0 1
dpa_on_off 0 1

Top Block@node19-20

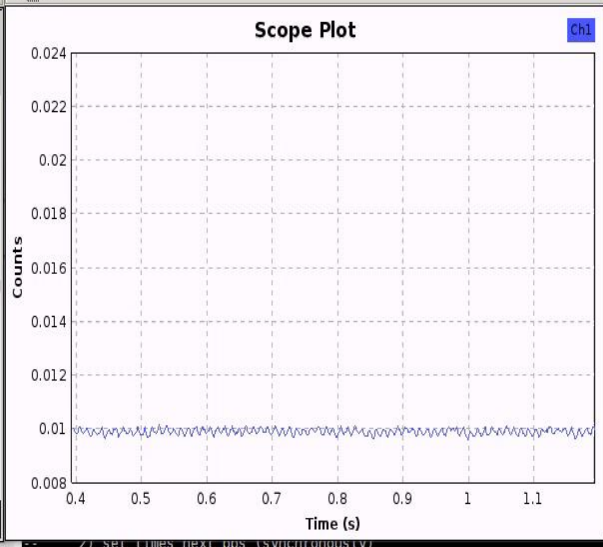
on_off 0 1
com_control 0 1



Persistence
Analog Alpha: 0.0994
Axes Options
Secs/Div:
Counts/Div:
Y Offset:
T Offset:
Autorange
Channel Options
Ch1 | Trig
Coupling: DC
Marker: Line Link
Stop

Top Block@node14-7

on_off 0 1
com_control 0 1



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Stop

```
Using Volk machine: sse4_2_64_orc
Input is 10.000000 ,rpl is 0.057653, random phase is 0.057653,Angel is 0.057653
```

Disable this terminal from "MultiExec" mode

```
Using Volk machine: avx_64_mmx_orc
Input is -10.000000 ,rpl is 0.000000, random phase is -0.254011,Angel is -0.254011
```

Disable this terminal from "MultiExec" mode

```
Loading: "tx_node_ekf_2.grc"
>>> Done

Showing: "/root/gr-howto/examples/tx_node_ekf_2.grc"

Generating: "/root/gr-howto/examples/top_block.py"

Executing: "/root/gr-howto/examples/top_block.py"

linux; GNU C++ version 4.8.4; Boost_105400; UHD_003.010.001.000-0-unknown

-- Opening a USRP2/N-Series device...
-- Current recv frame size: 1472 bytes
-- Current send frame size: 1472 bytes
--     1) catch time transition at pps edge
--     2) set times next pps (synchronously)
Using Volk machine: avx_64_mmx_orc
Input is 10.000000 ,rpl is 0.057653, random phase is 0.057653,Angel is 0.057653
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Disable this terminal from "MultiExec" mode

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